FLEXIBLE NET APPROACH FOR STEREO MATCHING

Victor B. Kostousov, Ilya L. Molochnikov*

Institute of Mathimatics and Mechanics. Ural's Branch of RAS. RUSSIA.

KEY WORDS: Stereo matching, Photogrammetry, Edge Detection, Occlusion.

ABSTRACT:

The principal function of any automated stereophotogrammetry algorithm is to match corresponding points in a stereo pair. A lot of investigations in this area have been made but problem of corresponding points in considerable occlusions hadn't solved yet. As a rule we meet essential occlusions in a city area photos, where usual correlation methods are inapplicable. This work introduces new approach to stereo matching problem solution that autonomously constructs the net of corresponding points. The algorithm is based on comparison of intensity profiles extracted from left and right frames. Each profile is presented by pixel sequence along line between two nodes of the net. We construct function which close to zero when profiles are projections of the same line segment from spatial scene. The technique takes account of intensity errors appeared because of perspective photos digitalizing where applying of merely pixel correlation is incorrect. We suggest iterative optimization algorithm which moves nodes of the net. After stabilization of the algorithm every node gives pair of corresponding points. Presence of relationship between nodes gives more useful information in contrast to disjoint spatial points set obtained by ordinary methods. Considerable occlusions appear usually on projections of spatial object edges. That's why we modify initial net configuration accordingly to detected edges on images before iterative process has started. Obtained experimental results demonstrate applicability of the method.

1. METHOD DESCRIPTION

The investigation concerns a problem of 3D scene reconstruction by stereo pair. The main problem is to determine the set of corresponded points on stereo pair frames for spatial coordinates reconstructing.

A lot of investigations in this area have been made (Tzay Y. Young, 1994, Victor B. Kostousov, 1997) but problem of corresponding points in considerable occlusions hadn't solved yet.

This work introduces new approach to stereo matching problem solution that autonomously constructs the net of corresponding points.

The algorithm is based on comparison of intensity profiles extracted from left and right frames. Each profile is presented by pixel sequence of line segment on raster image. In program realization we use Brezenheim's algorithm with 8 neighbor's representation. As result of profiles extraction we receive two set of intensity values. Amounts of pixels in left and right profiles are different as a rule. Fig.1 demonstrates profiles appearance. It is more likely that profiles are projections of the same line segment from spatial scene if they are similar.

Let $P^l = \left((x,y)_1^l, (x,y)_2^l\right)$ is profile from left frame defined by start $(x,y)_1^l$ and finish $(x,y)_2^l$ coordinates. And $P^r = \left((x,y)_1^r, (x,y)_2^r\right)$ is profile from right frame, analogously.

Let f,g is intensity functions on left and right frames, $\{l_i\}_{i=1}^{L}$ is sequence of pixel coordinates of left profile, $\{r_j\}_{j=1}^{R}$ is sequence of pixel coordinates of right profile.

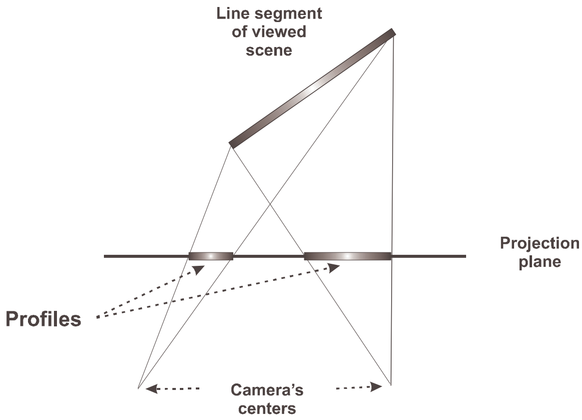

Fig.1 Line segment of scene with intensity variation and it projections on stereo pair.

Without loss of generality we assume $L < R$ and construct new sequence $\{r_i^{'}\}_{i=1}^{L}$, where

$$r_i^{'} = (r_R - r_1)\frac{i}{L} + r_1 .$$

According to new sequence we calculate difference function of two profiles:

$$D\left(P^l, P^r\right) = \sqrt{\frac{1}{L}\sum_{i=1}^{L}\left(f(l_i) - g^{'}(r_i^{'})\right)^2}$$

where $g^{'}$ is linear interpolation of g.

In that way, when profiles P^l and P^r are projections of the same line segment from spatial scene then value of function $D(P^l, P^r)$ is close to zero. Therefore, we use this function as measure of profiles similarity.

Now we pass to constructing of the net. Let $N_i = ((x,y)_i^l, (x,y)_i^r)$ is pair of points form left and right frames correspondingly, $N = \{N_i\}_{i=1}^n$ is set of nodes and $E = \{(N_i, N_j)\}$ is set of edges, then $G = (N, E)$ is the net on stereo pair. We should note that every edge $(N_i, N_j) \in E$ gives a pair of profiles and we declare weight for every edge:

$$D(N_i, N_j) \equiv D(P^l, P^r),$$

where P^l, P^r begin in node $N_i = ((x,y)_i^l, (x,y)_i^r)$ and end in node $N_j = ((x,y)_j^l, (x,y)_j^r)$.

On the whole net we construct functional

$$D(G) = \frac{1}{\|E\|} \sum_{(N_i, N_j) \in E} D(N_i, N_j).$$

The functional estimates value of difference of profiles which initiated by the net. The searching of the functional minimum by drifting of left or right parts of nodes will indicate the coordinates of corresponding points.

As a result of construction we produce functional of *2n* variables. It is impossible to suppose some smoothness of $D(G)$ on arbitrary images, therefore in practical realization we use analog of coordinate-wise optimization. For every node the algorithm estimates every point in vicinity of right part of the node and selects the point for new position which minimizes functional value. Iterative process of this step gives optimization algorithm that follows local minimum of constructed functional.

2. ALGORITHM OF FLEXIBALE NET

1. Initialization of the net
2. Calculation of new position for right part of every node. These positions deliver minimum for functional $D(G)$ relative to current allocation of the net.
3. if $D(G)$ is not decreasing, then Stop, else moves right parts of nodes in new positions and go to Step 2.

Initialization of the net begins with evenly filling of left frame by certain amount of nodes. Right parts of nodes are placed in the same coordinates with offset by average parallax. Set of edges is enlarged by connection of nodes in given surroundings so that every node had no less then 3 neighbors.

3. EXPERIMANTAL RESULTS

3.1 Model scene.

Modeled stereo pair represents one-color cylinder. It images are received by method of backward ray tracing, which imitate realistic photo. Frames of the stereo pair have not texture elements and pass convexity of cylinder by physical likely intensity distribution.

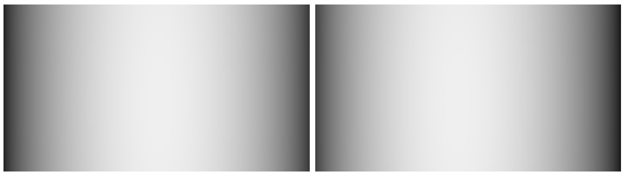

Fig.2 Modeled stereo pair of one-color cylinder in parallel illumination.

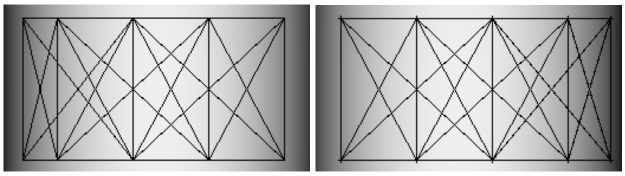

Fig. 3 Initial position of 10 nodes net.

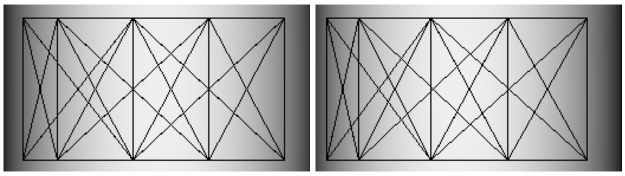

Fig.4 End position of the net after 6-th iteration of algorithm.

On synthetic images described algorithm convergences in 5 — 10 iteration. Relative error in reconstructed heights is less then 5%.

3.2 Real stereo pair. Experiment without occlusion zone.

For experimental estimation of algorithm we have used real photos also. It was obtained by one digital camera with sequent offset in front of stationary scene. Received images have 640x480 resolutions and do not pass prior processing. The stereo pair is not corrected for setting of epipolar lines along horizontal axis of frames as well.

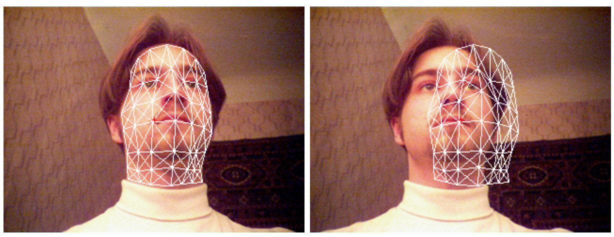

Fig.5 Initial position of the net on real stereo pair.

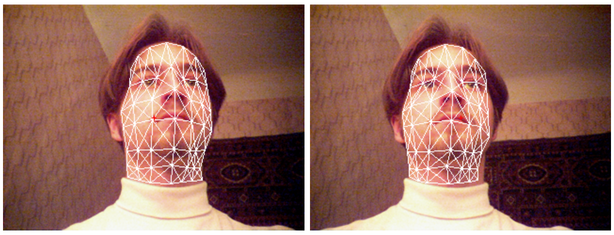

Fig.6 End position of the net.

Fig. 5 and 6 demonstrate initial and end position of the net. The net on the left frame is placed by hand so as to avoid essential occluding zone. Right parts of nodes are initially installed in the same coordinates as left parts. The net converges after 10-th iteration and indicates corresponding points.

3.3 Real stereo pair. Evenly filled by nodes.

Next images demonstrate the net that crossed essential occluded zones. The net fills frames evenly and occlusions have valued influence in results.

Fig.7 Stereo pair with essential occluded zones.

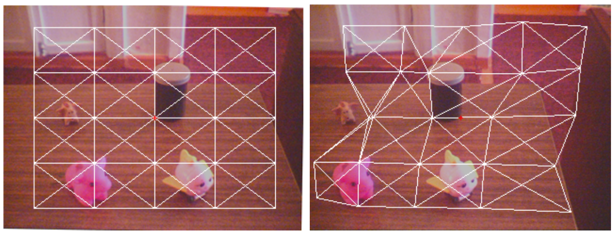

Fig.8 End position of the net after 8-th iteration.

After stabilization of the net we could see considerable errors in detection of position of 5, 10, 11 and 15 nodes. Nodes are numerated from left bottom corner to top per lines. Other nodes of the net take up correct positions.

4. OCCLUSION INFLUENCE

In present time we investigate convergence dependences from initial position of the net. Several methods of net modification are worked up which take account of occlusion zones. All of them are based on assumption: *essential occluded zones have arisen only on edges of scene objects.* That's why occluded zone on one of stereo pair frame will correspond to edge on another frame, i.e. difference in intensity level. But not all of intensity edges conform to occluded zones. Texture edges could be adduced as example. Thus the edge of the net which crosses intensity level difference could potentially passes occluded zone by one of it profiles. Weight function of this edge returns error value due to inexistence part in second profile. We propose method for solving of the problem. The edge should be cut in point of intersection with intensity level difference and we receive two additional disconnected nodes. This operation allows to slide new nodes apart and miss occluded zone between this nodes.

5. CONCLUSION

The investigation offers new method which based on profile comparison in contrast to individual pixel measurements. The method is independent of preprocessing procedures like epipolar alignment. Experimental results demonstrate applicability of given method of corresponding points searching. Potentially the method could takes to account occluded zones and further investigation of this approach allows us to construct the algorithm which works effectively in considerable occlusions.

6. ACKNOWLEDGMENTS

The studies were conducted with financial support of the International Science and Technology Center (project 99-1293), and Russian Foundation for Basic Research (project 00-01-00346).

7. REFERENCES

Tzay Y. Young, 1994, *Handbook of Pattern Recognition and Image Processing: Computer Vision*, Volume 2, Academic Press, USA.

Victor B. Kostousov, 1997, Solving the Problem of Stereo Pair Processing. *Proc. of the 4th Saint Petersburg Intern. Conf. On Integrated Navigation Systems. CSRI "Electropribor"*. S-Peterburg, Russia, pp.159-164.

Ingermar J. Cox, Sunita L. Hingormani, Satish B. Rao., 1996, A Maximum Likelihood Stereo Algorithm. *Computer Vision and Image Understanding.* Vol.63, No.3, May, pp.542-567.

Ilya L. Molochnikov, 2001, Methods of Spatial Scene Reconstruction by Stereo Pair. Proc. of the XXXII Regional Young Conf. "Problems of Fundamental and Applied Mathimatics", IMM UB RAS, Ekaterinburg, Russia, pp.239-243.